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UHF PROPAGATION MEASUREMENTS FROM ELEVATED TO BURIED ANTENNAS

F. G. Kimmett, et al

Institute for Telecommunication Sciences
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U.S. DEPARTMENT OF COMMERCE
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FOREWARD

This document, the final report covering task 2.7i is submitted by the Institute for Telecommunication Sciences, Boulder, Colorado, in accordance with contract FO4701-68-F-0072. The Air Force Project Officer was Captain M. A. Heimbecker of Headquarters Space and Missile Systems Organization, SMQNL-3, Air Force Systems Command, Norton Air Force Base, California.

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ABSTRACT

UHF PROPAGATION MEASUREMENTS FROM ELEVATED TO BURIED ANTENNAS

F. G. Kimmett, L. G. Hause, and P. L. McQuate

This report describes many of the UHF propagation characteristics between aircraft or satellites and buried antennas. A vertical monopole was used as a reference antenna, and the propagation characteristics of an annular slot and other antennas, omnidirectional in azimuth, were measured. The effects of reflecting planes used in conjunction with buried elementary antennas were measured. Site power gain patterns were measured from the buried antenna site at elevation angles up to 70°. These tests were made over a reasonably smooth plane, on paths of 0.03, 0.06, and 1 km, and at various transmitting antenna heights, with a helium-filled ballon. In some of the tests security fences were used.

TABLE OF CONTENTS

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This report describes many of the UHF propagation characteristics between aircraft or satellites and buried antennas. A vertical monopole was used as a reference antenna, and the propagation characteristics of an annular slot and other antennas, omnidirectional in azimuth, were measured. The effects of reflecting planes used in conjunction with buried elementary antennas were measured. Site power gain patterns were measured from the buried antenna site at elevation angles up to 70°. These tests were made over a reasonably smooth plane, on paths of 0.03, 0.06, and 1 km, and at various transmitting antenna heights, with a helium-filled ballon. In some of the tests security fences were used.

Key Words: Annular slot antenna, buried antennas, power gain patterns, UHF propagation.

1. INTRODUCTION

UHF buried antenna path-loss measurements were made during the summer of 1969 for ground point-to-point communications under various conditions as reported by Hause and Kimmett (1969). This report is a continuation of those buried antenna measurements, with emphasis on data applicable for communications from various buried antennas to aircraft. For aircraft height simulation, a maximum vertical angle of 6° was considered appropriate; however, measurements were made to approximately 70°.

The measurements were made at 415.9 MHz, and for compatibility with previous propagation data path loss measurements at a height of 0.75 m were conducted with the same monopole antenna used in previous area tests (Hause et al., 1969). This 0.75-m antenna is here referred to as the reference antenna.

Tests were made with and without a security fence in the transmission path.

2. PATH GEOMETRY AND SITE CONFIGURATION

The UHF propagation measurements were made at Table Mountain, located a few miles north of Boulder, Colorado (see fig. 1). A map (fig. 2) shows the contours of the test area and the placement of the receiving and transmitting sites. An overall view of the area is given in figure 3, showing path distances and placement of the security fence. Figure 4 shows path horizon photographs from the receiver site to the transmitter sites at A and B, with the security fence in place.

The security fence was 7 feet high and consisted of chain link No. 9 gauge wire. It was topped by three strands of wire placed on guides of 45°. One length of fence was placed perpendicular to the path from the receiver site to site A, and the other length perpendicular to the path to site B.

For the tests decribed in table 1, the transmitter sites are 1 km from the receiver site, with site A and site B on an arc 90° apart, with additional transmitting sites every 10° on this arc (fig. 2). For the tests presented in tables 2 and 3, the transmitting and receiving antennas are 60 and 30 m apart and are directly north of the receiver site.

A conical pit, 3.5 m in diameter and 3 m deep, was used at the receiving site for the placement of the antennas to be tested. The sides of this pit were lined with 6-mil plastic sheets, spanned by 2 x 6 inch wooden beams, and covered by ½ inch plywood.

To simulate buried conditions, a liquid dielectric (No. 2 diesel fuel oil) was used to completely fill the pit. This provided a homogeneous medium that the receiving antenna could be lowered into, a medium that produced very little change in dielectric constant and conductivity with changes in temperature and ion content. Dielectric constant was 2.27 and conductivity was 0.00005.

3. ANTENNAS

The receiving antennas used for these measurements are shown in the photographs in figure 5. The reference monopole antenna has been used in previous measurement programs (Hause et al., 1969); its pattern is shown in figure 6. The other receiving antennas were constructed to operate in fuel oil. Because of the difference in phase velocity, their size is approximately 0.707 of that of similar antennas designed to operate at 415.9 MHz in air. VSWR measurements were made at the operating frequency while each test antenna was immersed in fuel oil. VSWR as a function of frequency is shown for the annular slot antenna in figure 7.

Figure 8 shows the dimensions of the annular slot antenna, which was found to radiate approximately 92 percent of the forward power (VSWR 1.81). To reduce reflection interference from the sides of the fuel pit, the horizontal omnidirectional antenna (Scheldorf, 1949, and the quarter-wave monopole antennas were placed over a ground plane with a diameter equal to that of the top of the annular slot (66.3 cm). The horizontally polarized antenna and the quarter-wave monopole antenna over a ground plane were found to radiate approximately 92 percent (VSWR 1.76) and 91 percent (VSWR 1.86) of the forward power, respectively.

The antenna used for the transmitter was the same as the reference antenna previously referred to and is shown in figure 9. Its VSWR was 1.3, and it was the only transmitting antenna used during these tests.

4. EQUIPMENT AND OPERATIONS

The annular slot and horizontally polarized test antennas were operated with the plane of the antenna parallel to the surface of the fuel oil at the appropriate test depth. The horizontally polarized antenna was always placed with the open center of the "V" pointing directly toward site A. For the quarter-wave monopole, the top of the antenna was 12.5 cm above the ground.

The van housing the receiver, recording equipment, and signal generator, used in previous measurement programs, has been described by Hause et al. (1969). A battery-powered preamplifier, mounted at the base of the receiving antenna, provided about 45-dB gain and was used on all submerged antenna measurements.

The transmitter was battery powered and gave a maximum output of +11.5 dBm. A bottom view of the transmitter with its battery package is shown in the lower photograph of figure 9.

The transmitting assembly, weighing 4 pounds, was attached by swivels to a standard meteorological balloon (see figs. 9 and 10) inflated with helium to provide a lift of 7 pounds. The swivels permitted the balloon to rotate freely without affecting the attitude of the transmitting assembly. A nonmetallic guy line was attached to the upper swivel to maintain the balloon over the desired location.

The level of the signal received from the reference antenna at 0.75 m above ground, the immersed annular slot, and horizontally polarized antenna was recorded as the balloon raised the transmitting antenna to discrete heights between 3 and 110 m above ground. Azimuthal measurements were made from 10 transmitting sites located on an arc 1 km from the receiver site with the transmitting antenna raised to 10 m above ground.

Transmission loss values were recorded for the annular slot and the quarter-wave monopole antennas to vertical angles up to 70°, with the distance between the transmitting and receiving antennas kept constant at 30 m.

5. RESULTS AND COMPARISONS

The receiving antennas were designed for use within the fuel oil. They were not optimized to obtain the lowest VSWR possible at 415.9 MHz but, for transmission loss calculations, allowance for this mismatch was made. Transmission loss is here defined as the ratio between the power radiated at the transmitting antenna and the available power at a loss-free receiving antenna.

Path profiles are not presented; however, they may be drawn from figure 2. From figure 2, it is apparent that a plane through the receiver site, site A and site B, is closely approximated by the actual tilt of the land; therefore, for analysis, the area was considered to be a plane.

The site power gain patterns (see figs. 22 and 23) for the annular slot and quarter-wave monopole antennas were derived from the relationship $L_b = L_{bf} + G_T + G_{site}$, where L_b = basic transmission loss, L_{bf} = basic transmission loss in free space, and G_T and G_{site} are the gains of the transmitting antenna and of the site containing the test antenna, respectively. This equation is not considered proper at very low vertical angles for transmission over a smooth plane. To determine the smallest angle for which our results are valid, a check was made by applying this equation to the applicable data obtained with the annular slot antenna. The result of this check is shown in figure 24.

The data from the tests as listed in table 1 are shown in figures 11 through 16, and these results are compared in figures 17 and 18 with transmission loss a function of vertical angle; figure 19 shows transmission loss as a function of azimuthal angle. The levels received by the annular slot and horizontal omnidirectional antennas are 8-9 and 15-16 dB, respectively, below the level of the 0.75-m high reference antenna at a given vertical angle. It can be seen from figures 17 and 18 that for each site the shape of the transmission loss function for the reference antenna is very nearly that of each buried test antenna.

The security fence attenuates the signal about 1 to 2 dB; at very low angles, however, the fence appears to have negligible effect on the received signal level. With the fence near the receiving site (15 m), at high angles the signal was attenuated from 3½ to 4 dB.

The data for the tests listed in table 2 with the annular slot and quarter-wave monopole antennas are shown in figure 20.

Lowering the annular slot antenna from ground level to a depth of 1 m caused a decrease in signal level of about 1½ dB, while lowering the quarter-wave monopole to that level appeared to decrease the signal level by 3 dB. The signal level of the quarter-wave monopole was about 3 dB lower than the annular slot at a depth of 1 m.

Using a ground plane below the quarter-wave monopole decreased the depths of nulls caused by reflections from about 15 dB (Hause and Kimmett, 1969) to 4½ dB.

The data for the tests listed in table 3 are shown in figure 21, and the resulting site power gain (see IEEE, 1965) patterns are shown in figures 22 and 23.

The site containing the annular slot showed a maximum gain of about 1 dB above isotropic at 54 to 55°, while the site containing the monopole showed 0 dB at 52°.

6. CONCLUSIONS

Signal levels from buried antennas may be fairly accurately predicted from test results with elementary antennas in air at low heights (0.75 m above ground). This conclusion follows from the shape consistency of the curves in figures 17 and 18.

At very low angles, the security fence has slight effect on the signal level; at angles above ½° the fence generally causes an attenuation from 1 to 2 dB. This result was obtained at both fence distances. A greater attenuation is noted at high angles (approximately 6°) when the security fence is placed near the receiving antenna. This may require further investigation if these fences are to be placed at distances less than 15 m from a buried antenna.

The site power gain pattern of the annular slot and the quarter-wave monopole antenna appear to be quite similar, and if no interface reflections are present the performance of these two antennas could be expected to be within 2 to 3 dB, with the monopole having the lower gain, provided a material having a dielectric constant of approximately 2 is used.

Close agreement (within 2 dB, see fig. 24) is noted between the site power gains derived for the various path distances. This would imply that, at 30 m or more, changes in site power gain with distance are negligible for angles greater than 2°.

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Scheldorf, M. W. (1949), Multi-V antenna for F-M broadcasting, Electronics, 94-96.

IEEE (1965), Test Procedure fo: Antennas, IEEE No. 149, 32 (The Institute for Electrical and Electronics Engineers, Inc., Box A, Lenox Hill Station, New York, N. Y. 10021).

Table 1. Air-to-Ground Transmission Loss Tests Over 1-km Paths.

TEST NO.	RECEIVER ANTENNA TYPE	ANTENNA HEIGHT		RANGE OF VARIABLE	SECURITY FENCE	TRANSMITTER SITE
		RECEIVER (in Meters)	TRANSMITTER (in Meters)			
1	Ref Monopole	3/4	Various	5 to 110 m	without	A
2	Annular Slot	-1	Various	5 to 110 m	without	A
3	Horiz Omni	-1	Various	5 to 110 m	without	A
4	Annular Slot	-1	Various	5 to 110 m	with	A
5	Horiz Omni	-1	Various	5 to 110 m	with	A
6	Ref Monopole	3/4	Various	5 to 110 m	without	B
7	Annular Slot	-1	Various	5 to 110 m	without	B
8	Horiz Omni	-1	Various	5 to 110 m	without	B
9	Annular Slot	-1	Various	5 to 110 m	with	B
10	Horiz Omni	-1	Various	5 to 110 m	with	B
11	Ref Monopole	3/4	10	0 to 90°	without	A to B
12	Annular Slot	-1	10	0 to 90°	without	A to B
13	Horiz Omni	-1	10	0 to 90°	without	A to B
14	Annular Slot	-1	10	0 to 90°	with	A to B
15	Horiz Omni	-1	10	0 to 90°	with	A to B

Note: These tests were made for various receiving antennas, transmitting antenna heights, and path azimuth angles, with and without security fences.

Table 2. Tests to Investigate Transmission Loss vs. Depth.

TEST Nº	RECEIVER ANTENNA TYPE	ANTENNA HEIGHT RECEIVER (in meters)	ANTENNA HEIGHT TRANSMITTER (in meters)	PATH DISTANCE (in meters)
16	Annular Slot	-2 to 0	3	60
17	$\frac{1}{4}$ Wave Monopole over a ground plane	-2 to 0	3	60

Table 3. Tests to Determine Site Power Gain Patterns.

TEST Nº	RECEIVER ANTENNA TYPE	ANTENNA HEIGHT RECEIVER (in meters)	ANTENNA HEIGHT TRANSMITTER (in meters)	PATH DISTANCE (in meters)
18	Annular Slot	-1	1 to 28*	30
19	$\frac{1}{4}$ Wave Monopole over a ground plane	-1	1 to 28*	30

*Distance between receiving and transmitting antennas was held constant.

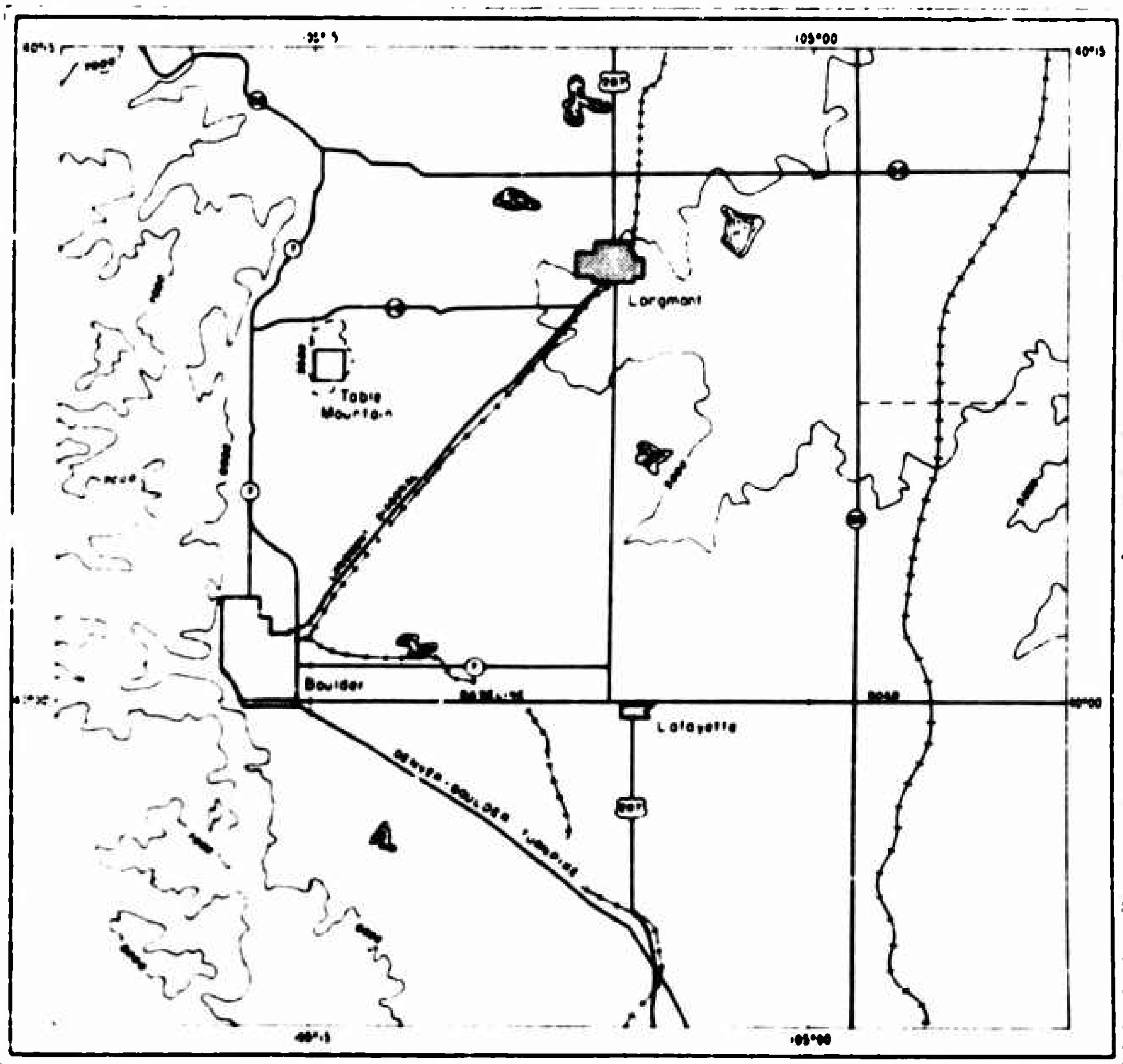


Figure 1. UHF propagation measurement field test area in Colorado.

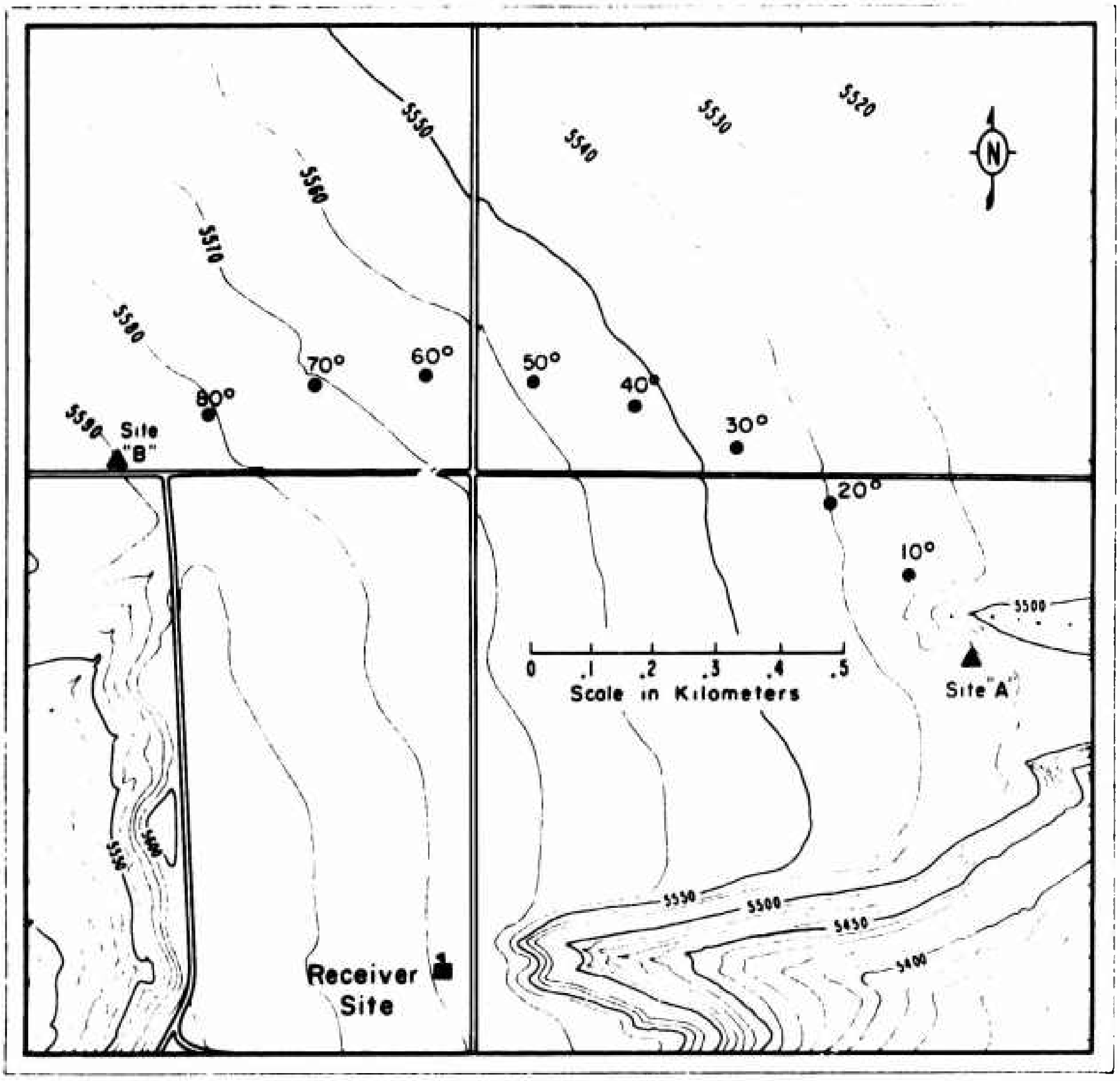


Figure 2. Table Mountain test area.

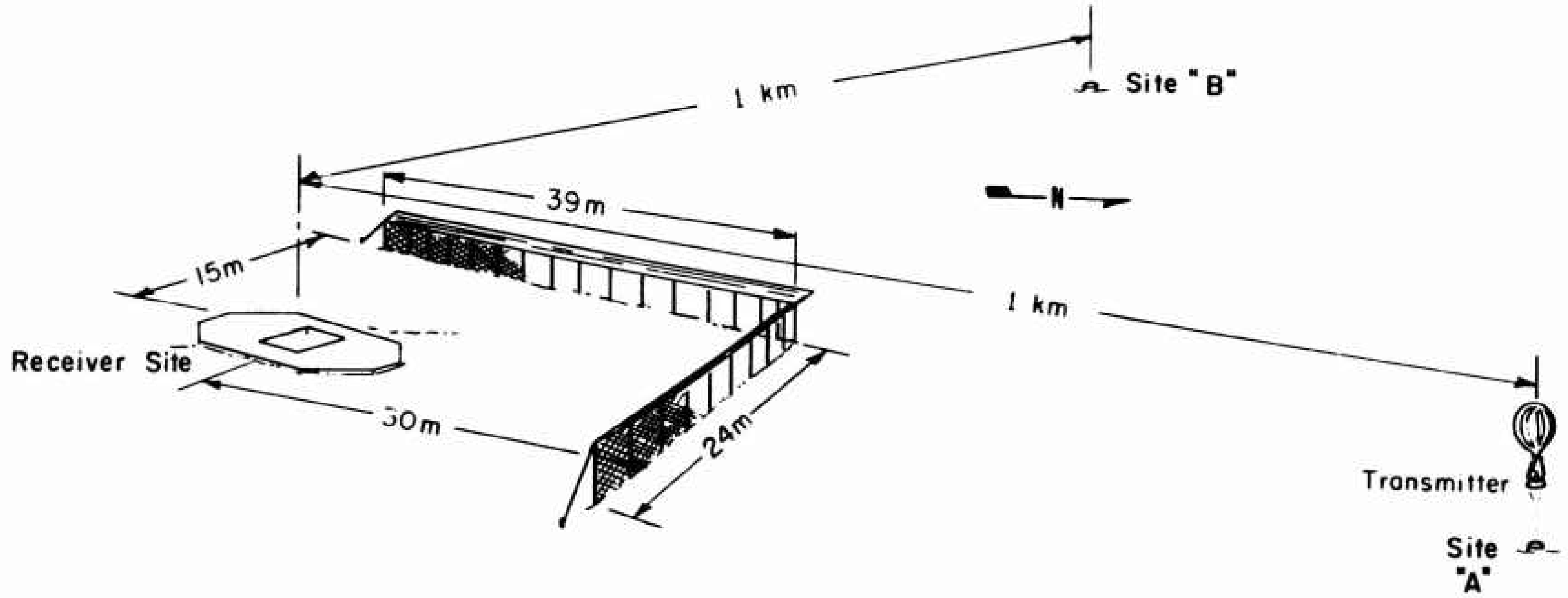


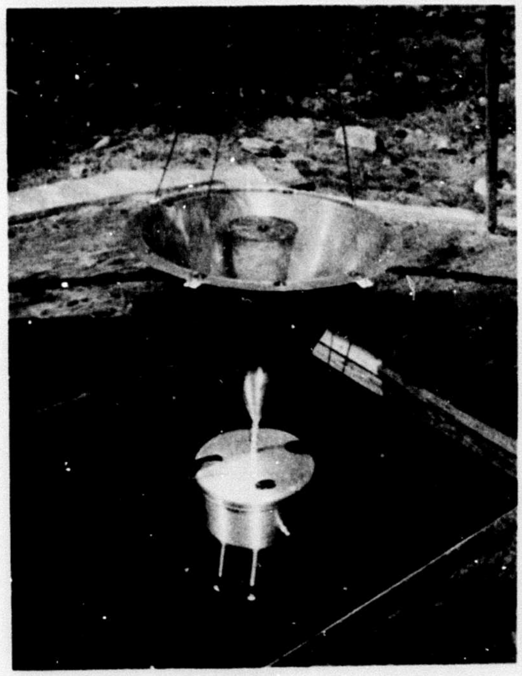
Figure 3. Site and security fence locations showing distances at Table Mountain test area.

From receiver site toward site A

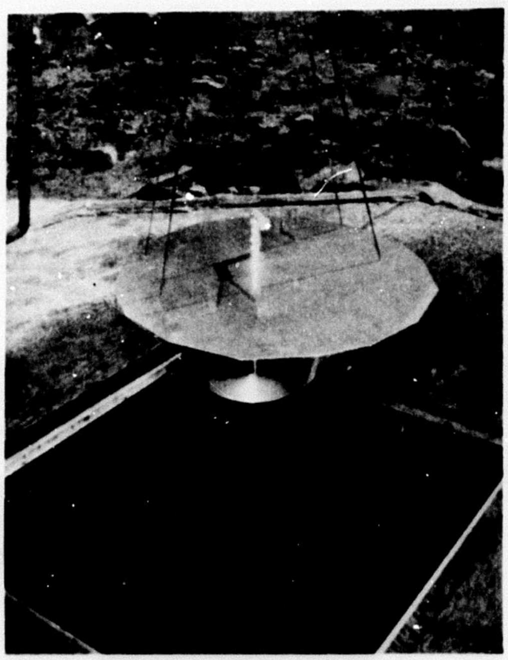
From receiver site toward site B

Figure 4. Path horizon photographs with security fence,

Reference monopole



Annular slot



Horizontal omni-directional
with reflecting plane

1/4 wave monopole with
reflecting plane

Figure 5. Receiving antennas.

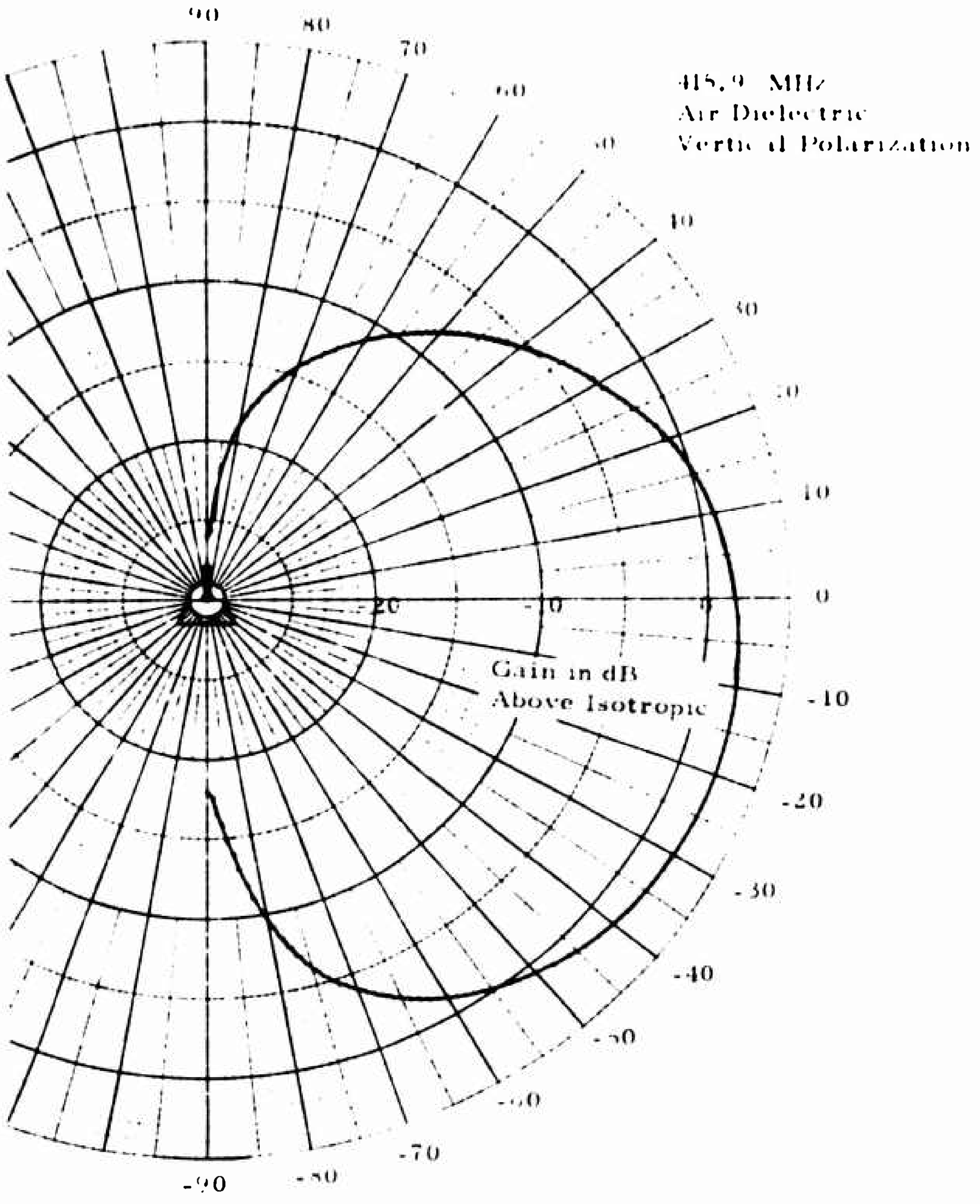


Figure [illegible]. Antenna pattern for the reference antenna and the transmitting monopole.

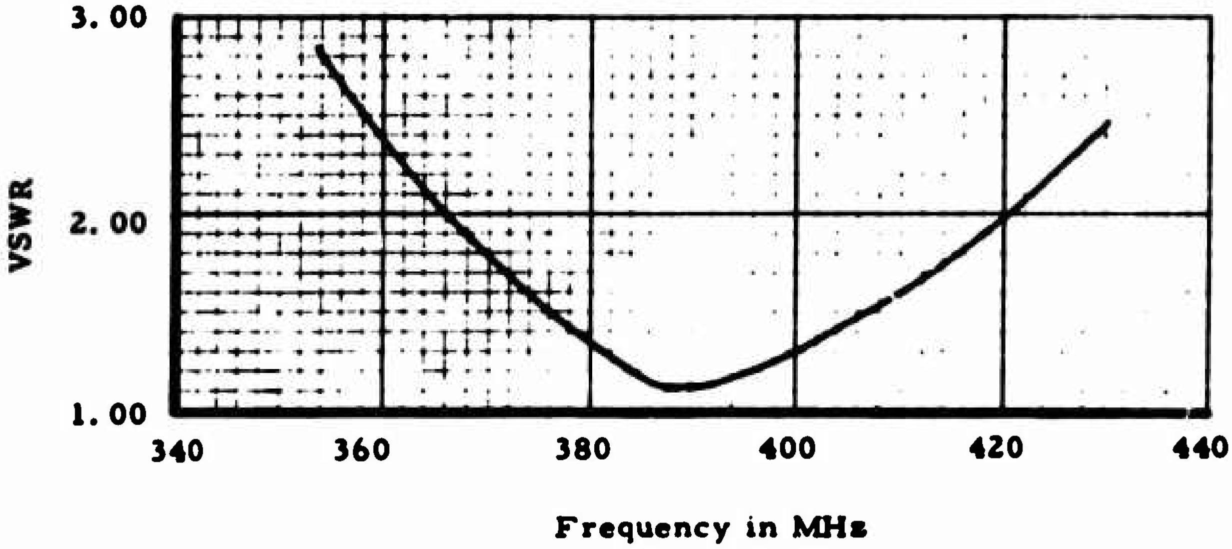


Figure 7. VSWR vs frequency for the annular slot antenna submerged in fuel oil.

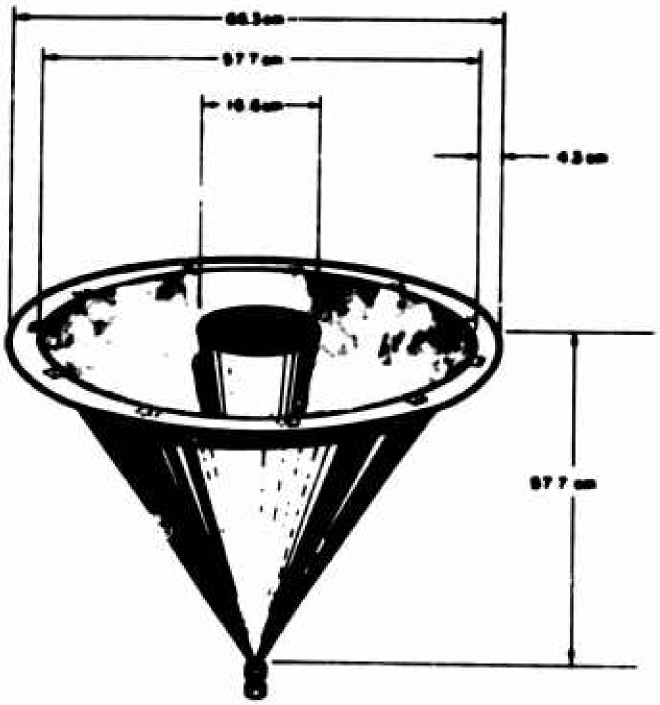
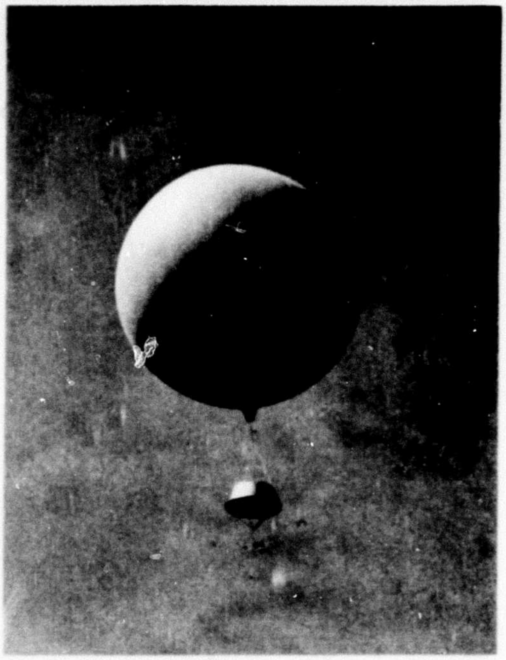
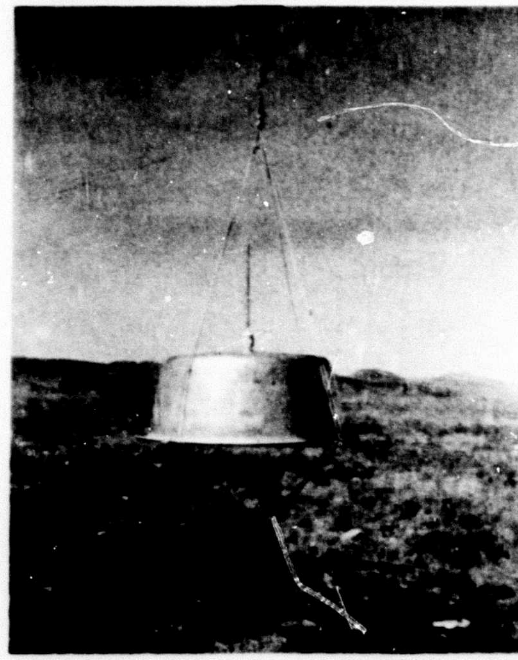


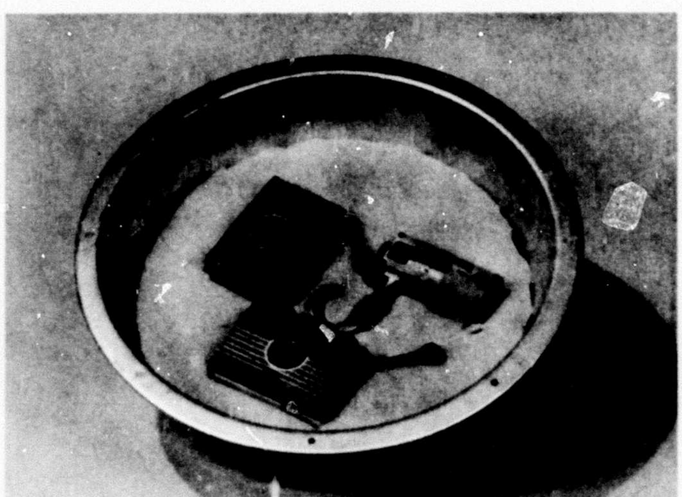
Figure 8. Dimensions of the annular slot antenna used in fuel oil.



Balloon and transmitter assembly in elevated position



Monopole antenna with transmitter housing



Bottom, open view of housing

Figure 9. Transmitting equipment.

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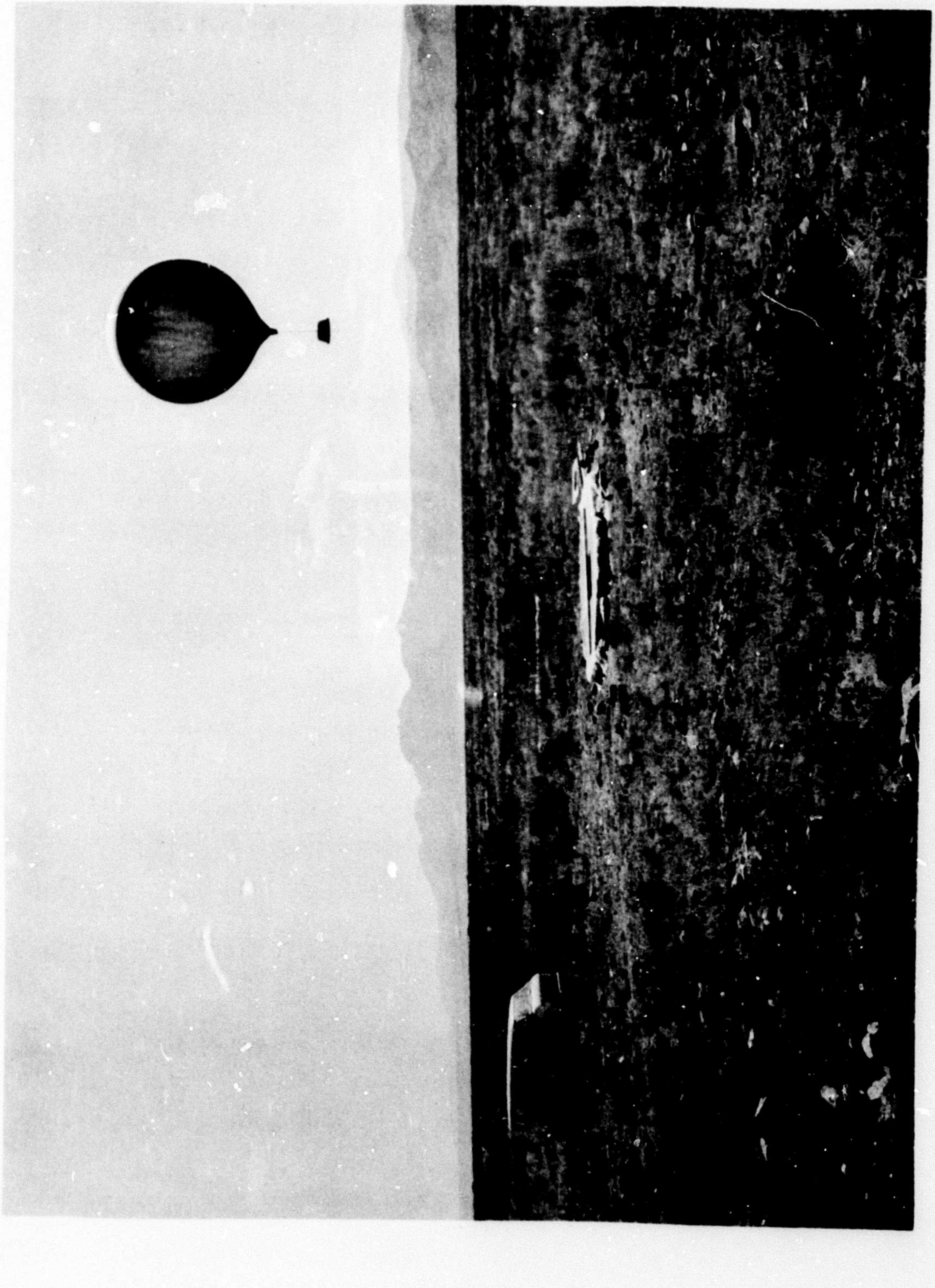

Figure 10. Receiving area during site power gain pattern tests.

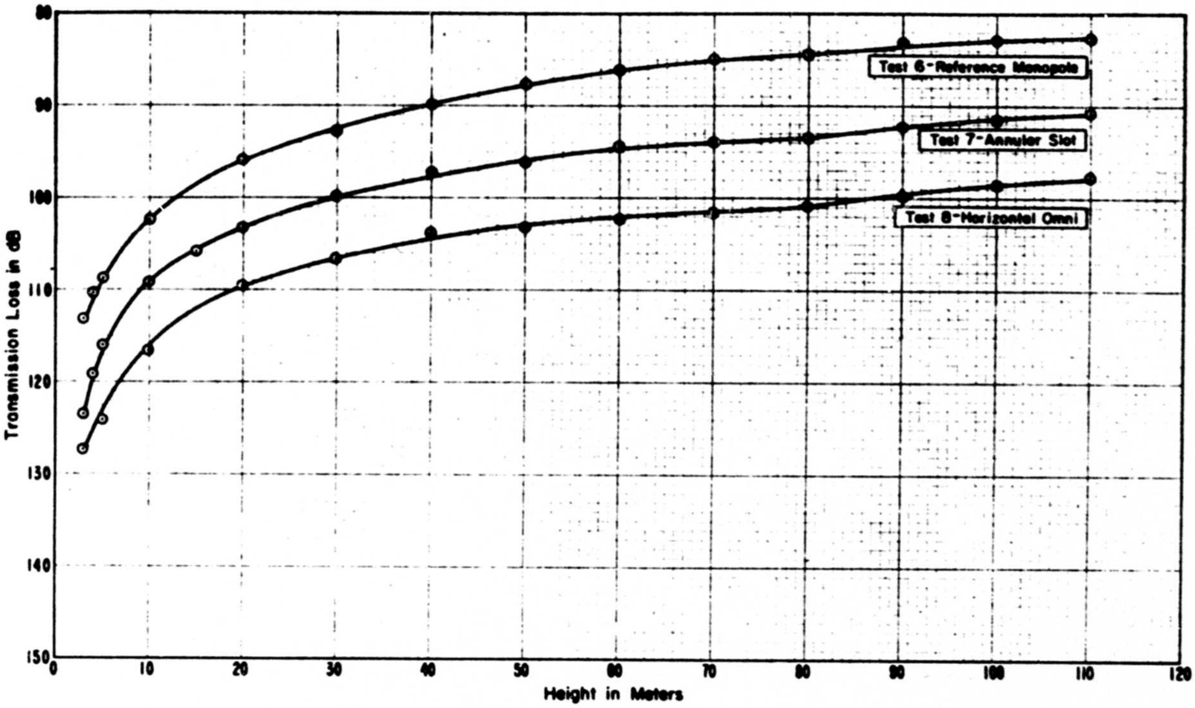

Figure 13. Receiver site to site B vertical tests without security fence.

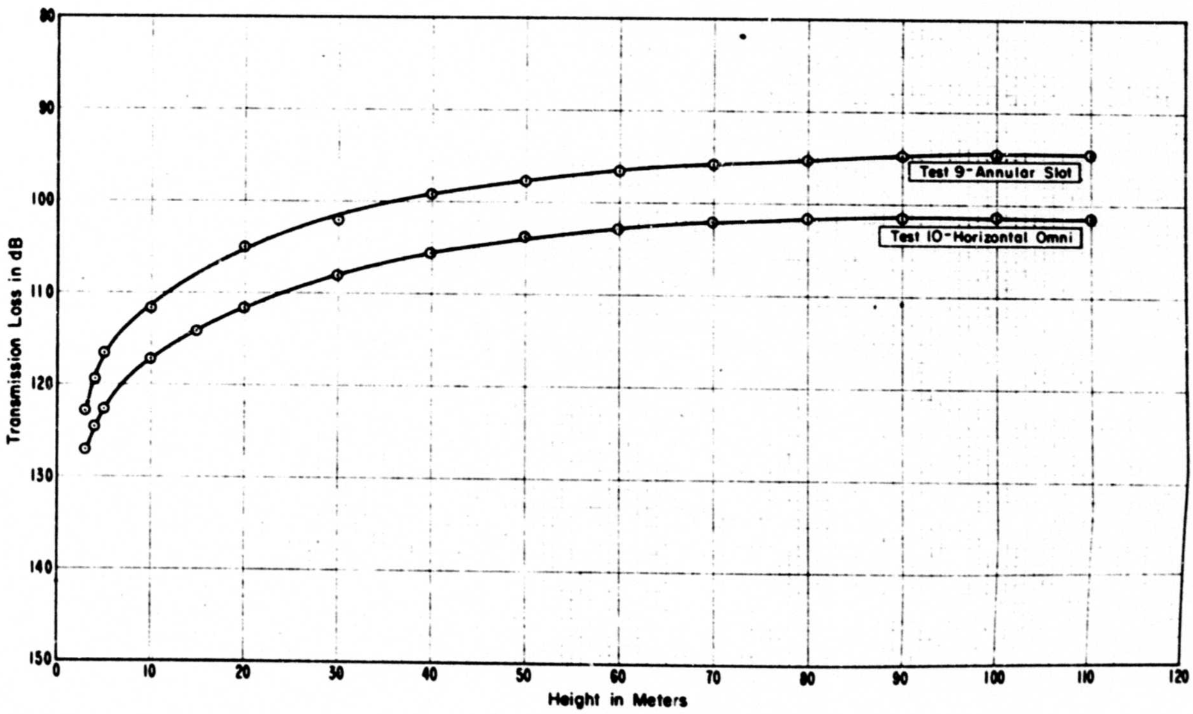

Figure 14. Receiver site to site B vertical tests with security fence.

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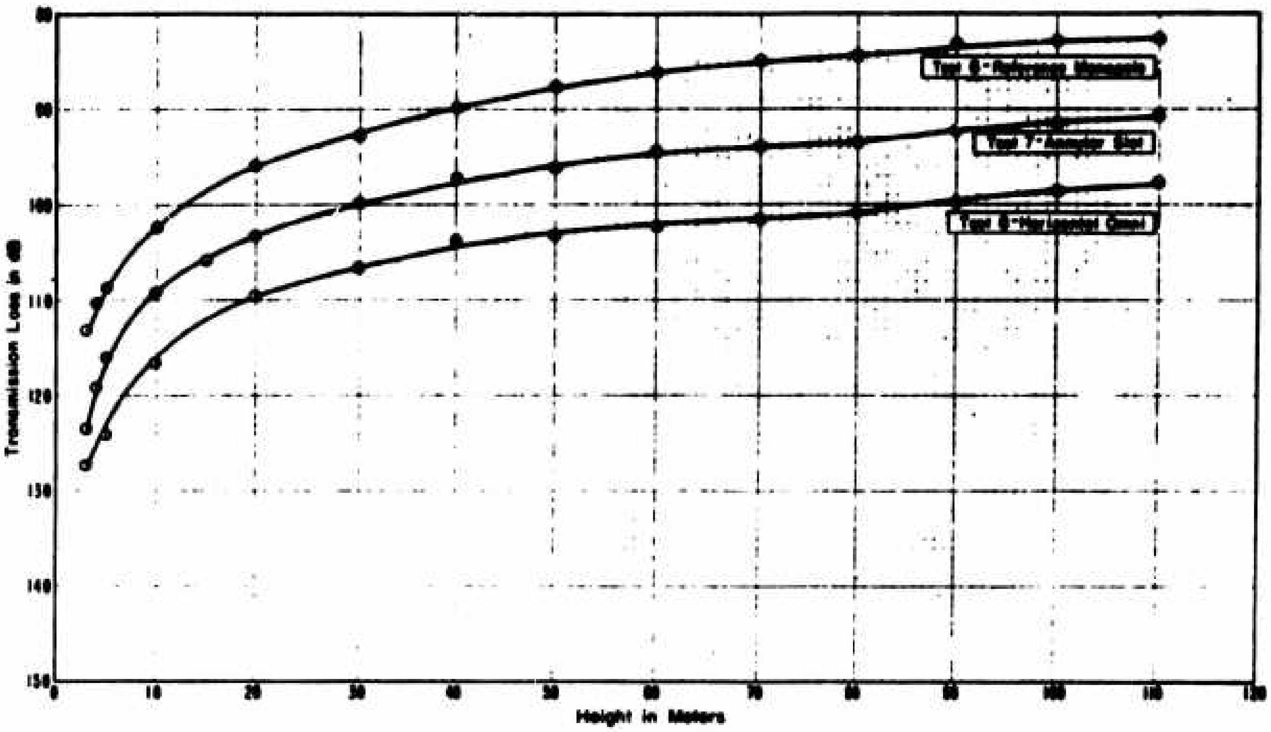

Figure 13. Receiver site to site B vertical tests without security fence.

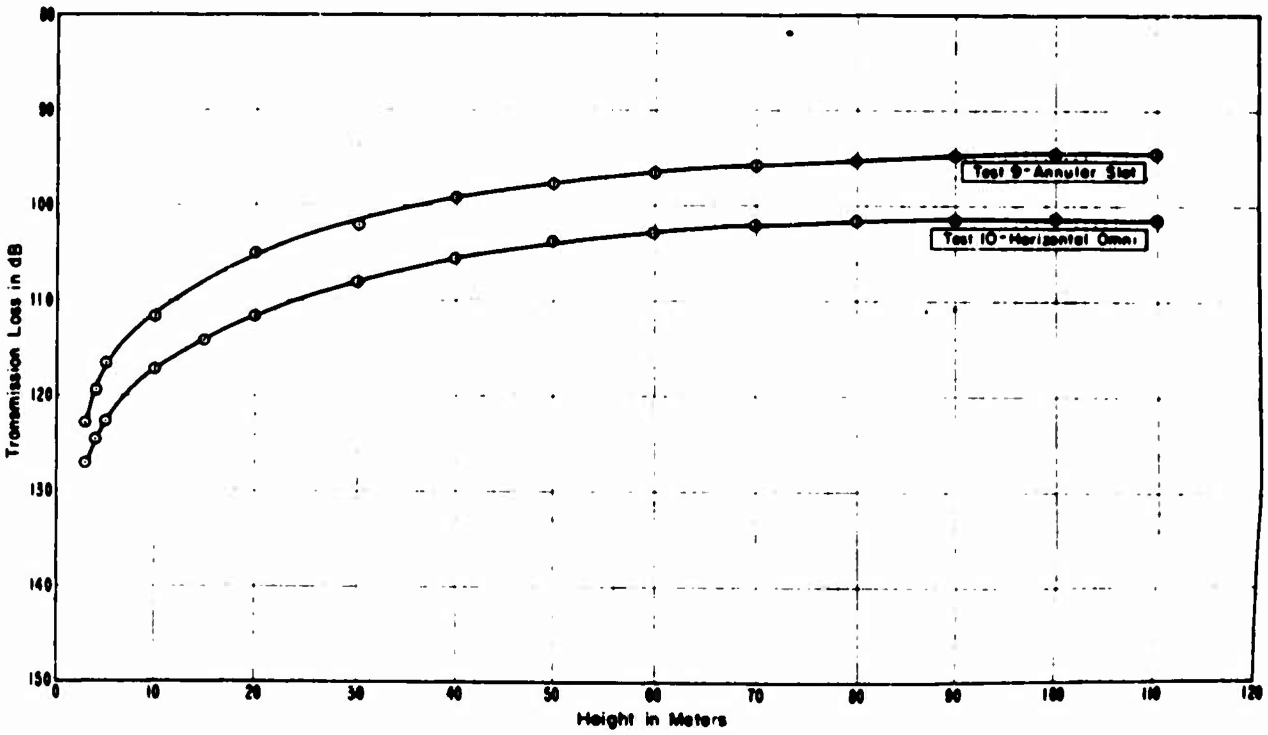

Figure 14. Receiver site to site B vertical tests with security fence.

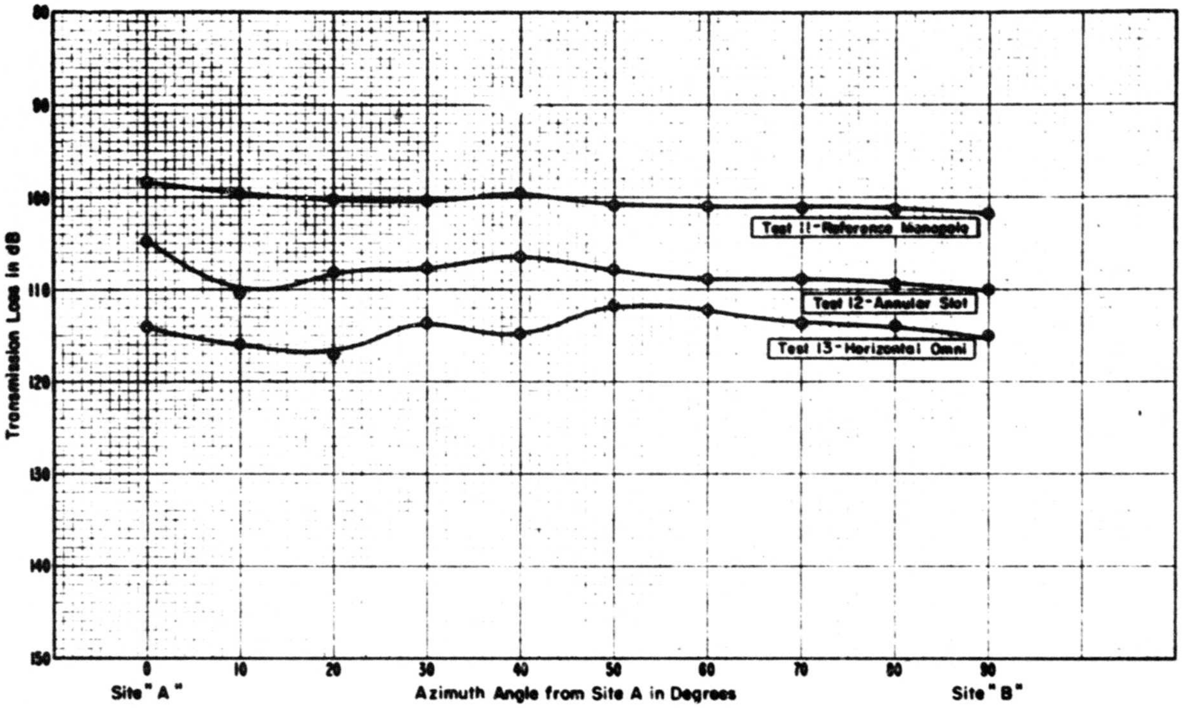

Figure 15. Re eiver site to azimuthal sites on an arc from site A to site B without security fence.

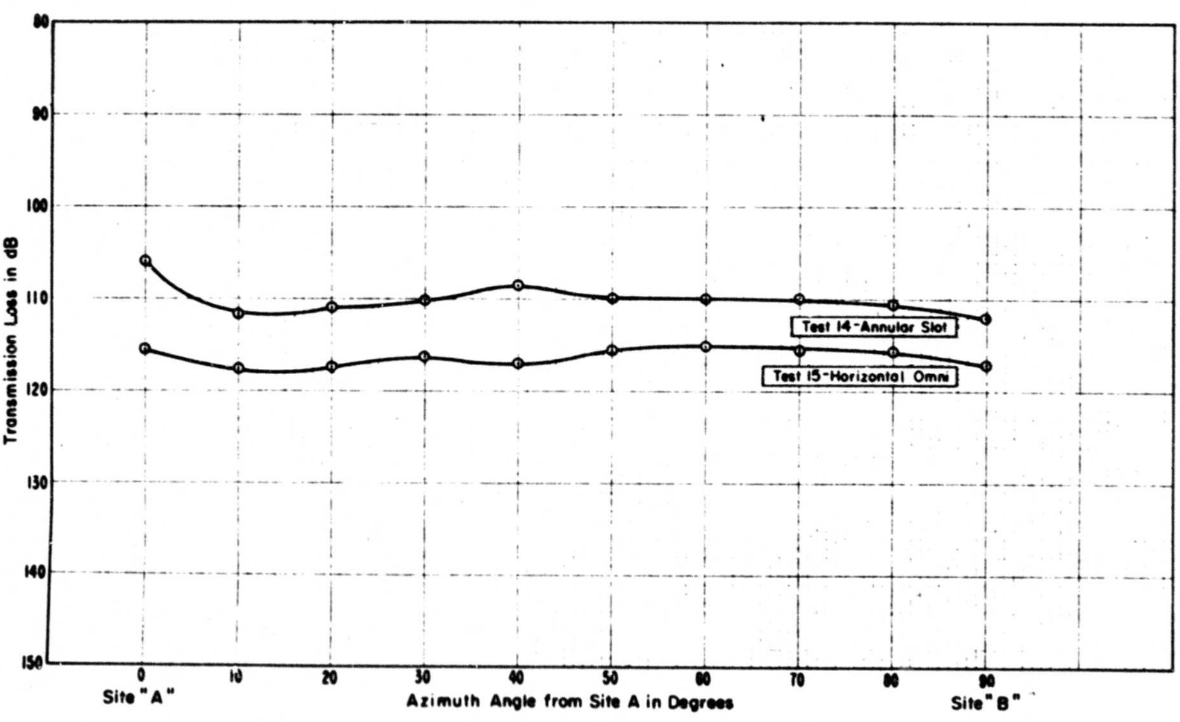

Figure 16. Receiver site to azimuthal sites on an arc from site A to site B with security fence.

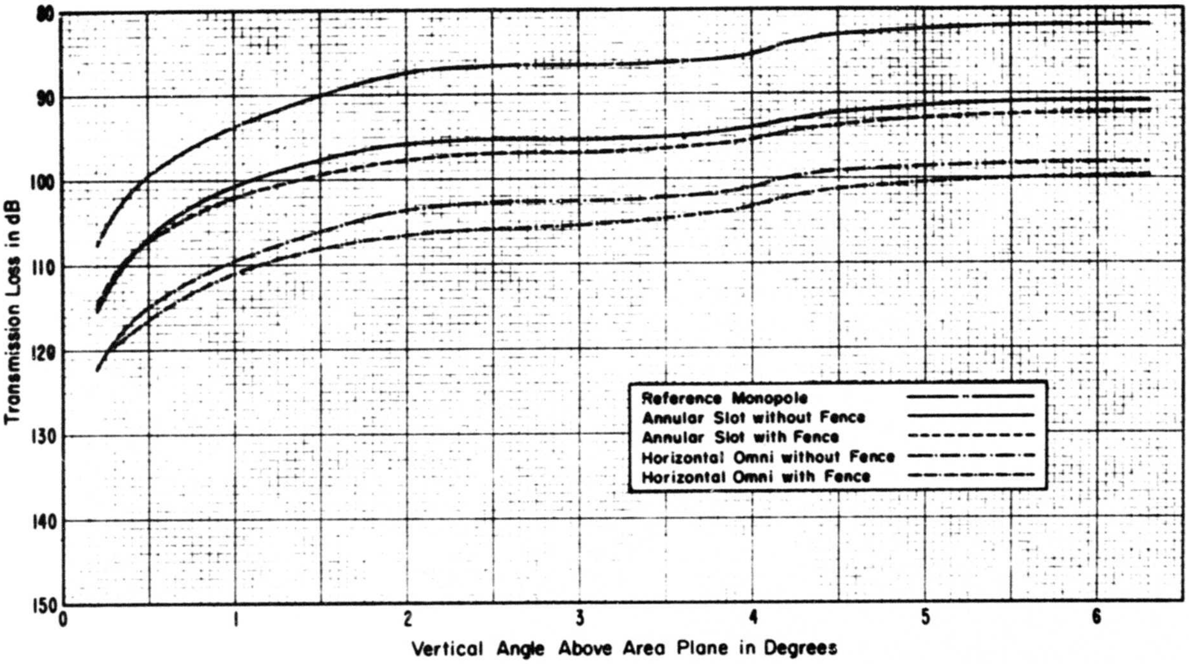

Figure 17. Transmission loss vs. vertical angle from receiver site to site A.

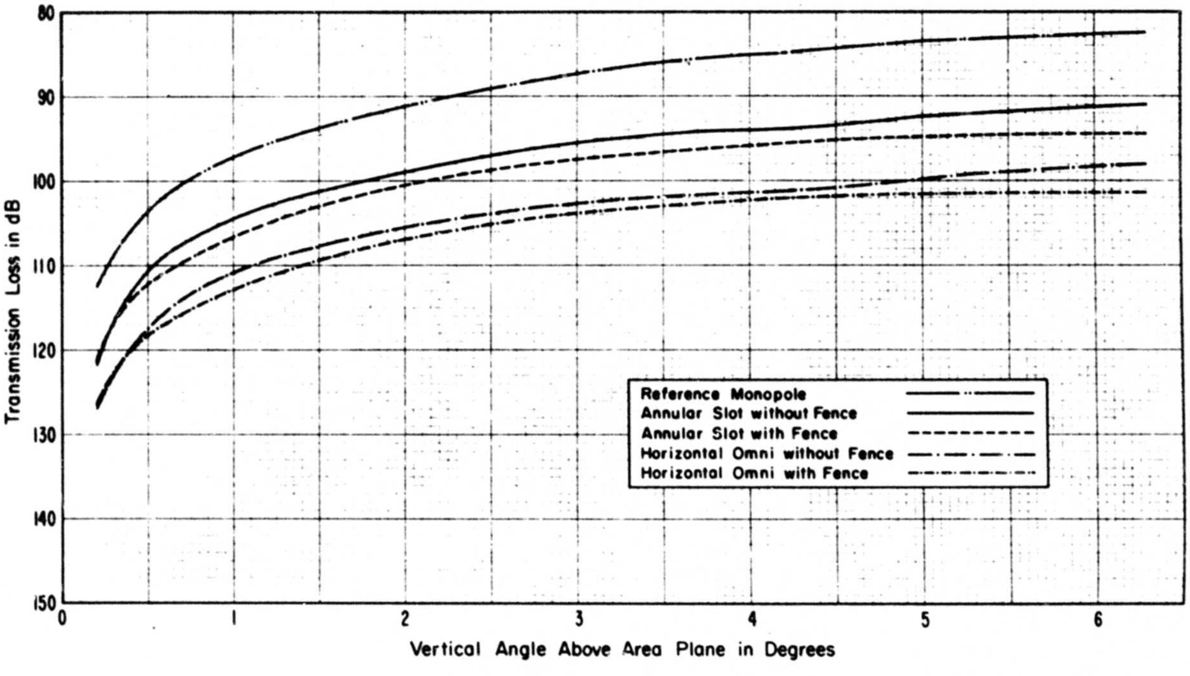

Figure 18. Transmission loss vs. vertical angle from receiver site to site B.

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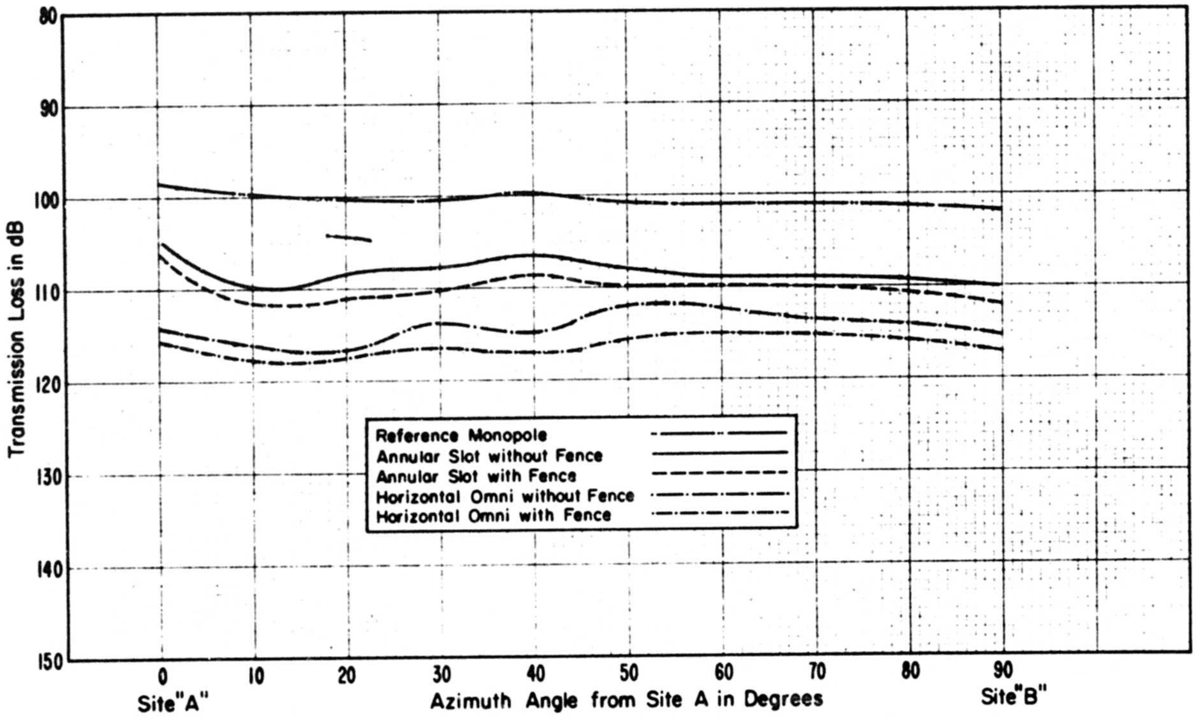

Figure 19. Transmission loss vs. azimuth angle from receiver site to azimuthal site on an arc from site A to B.

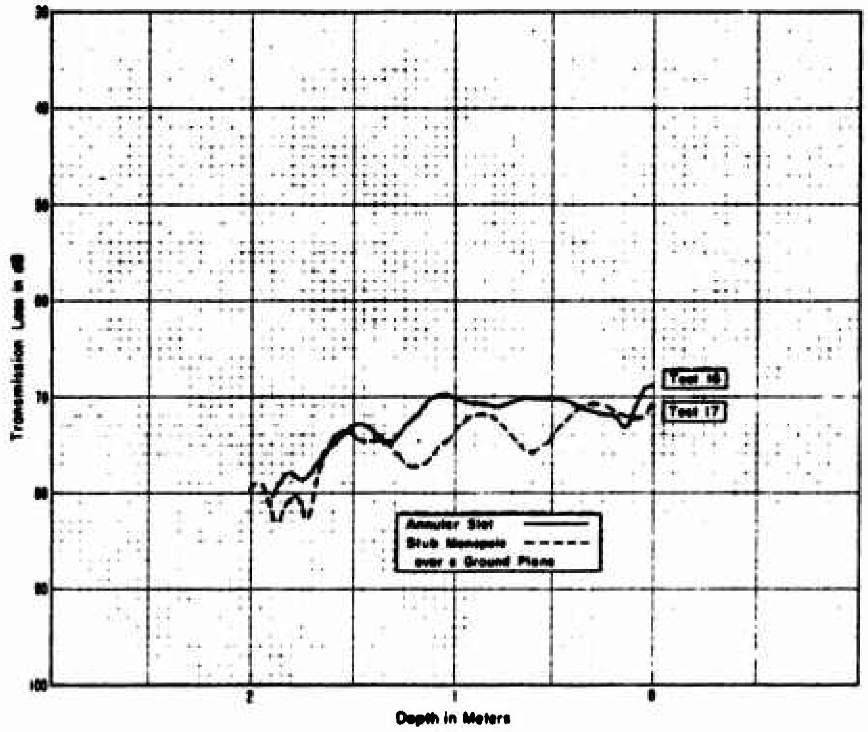

Figure 20. Transmission loss vs. depth measurement for annular slot and 1/4 wave monopole antennas.

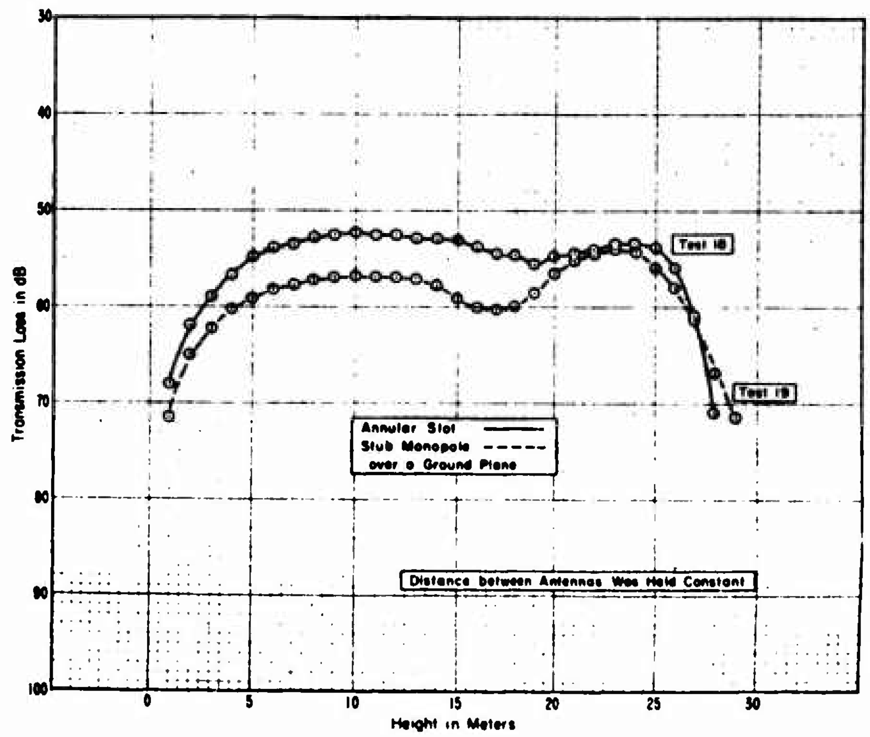

Figure 21. Tests for site power gain pattern of the annular slot and 1/4 wave monopole antennas.

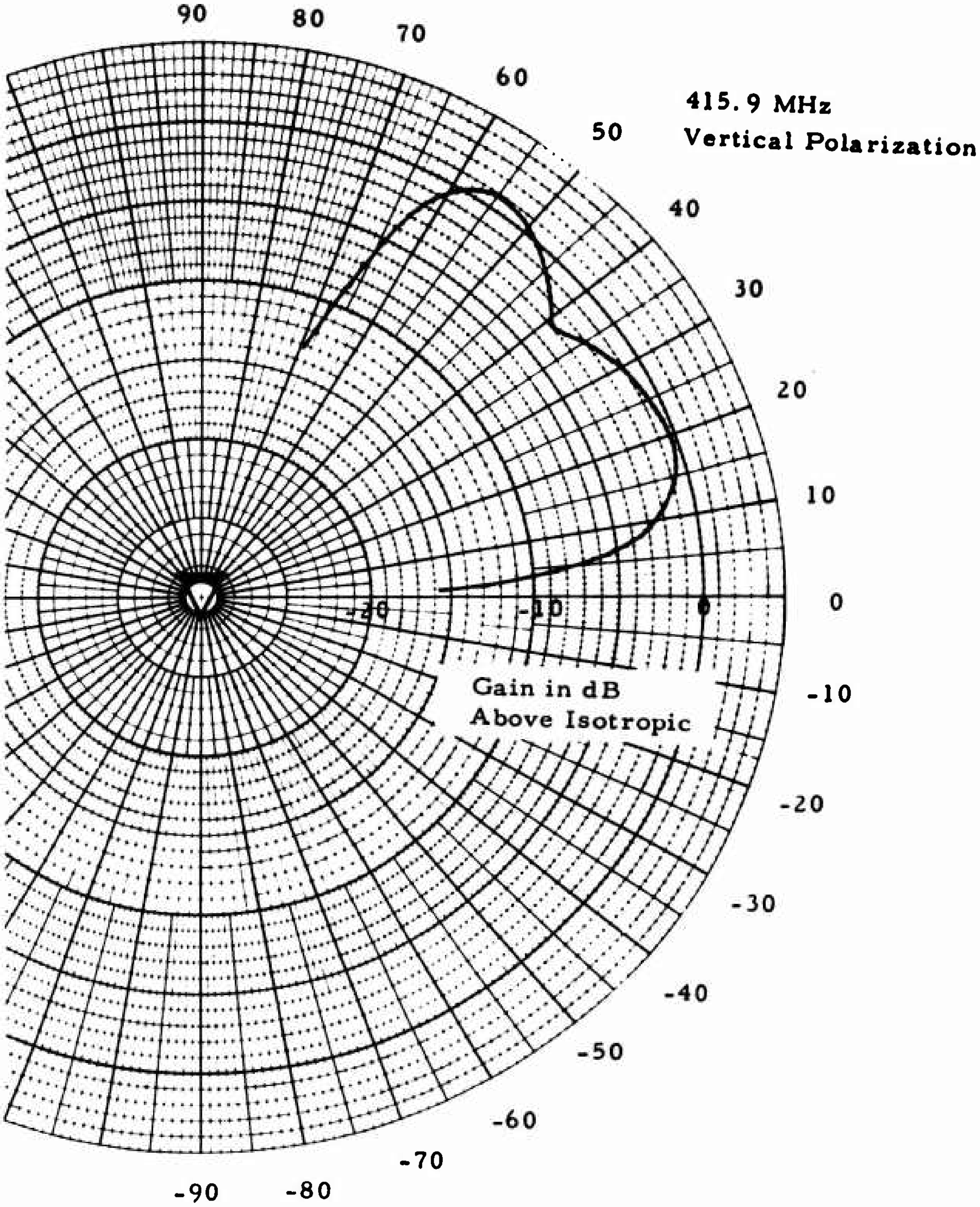

Figure 22. Site power gain pattern for the annular slot.

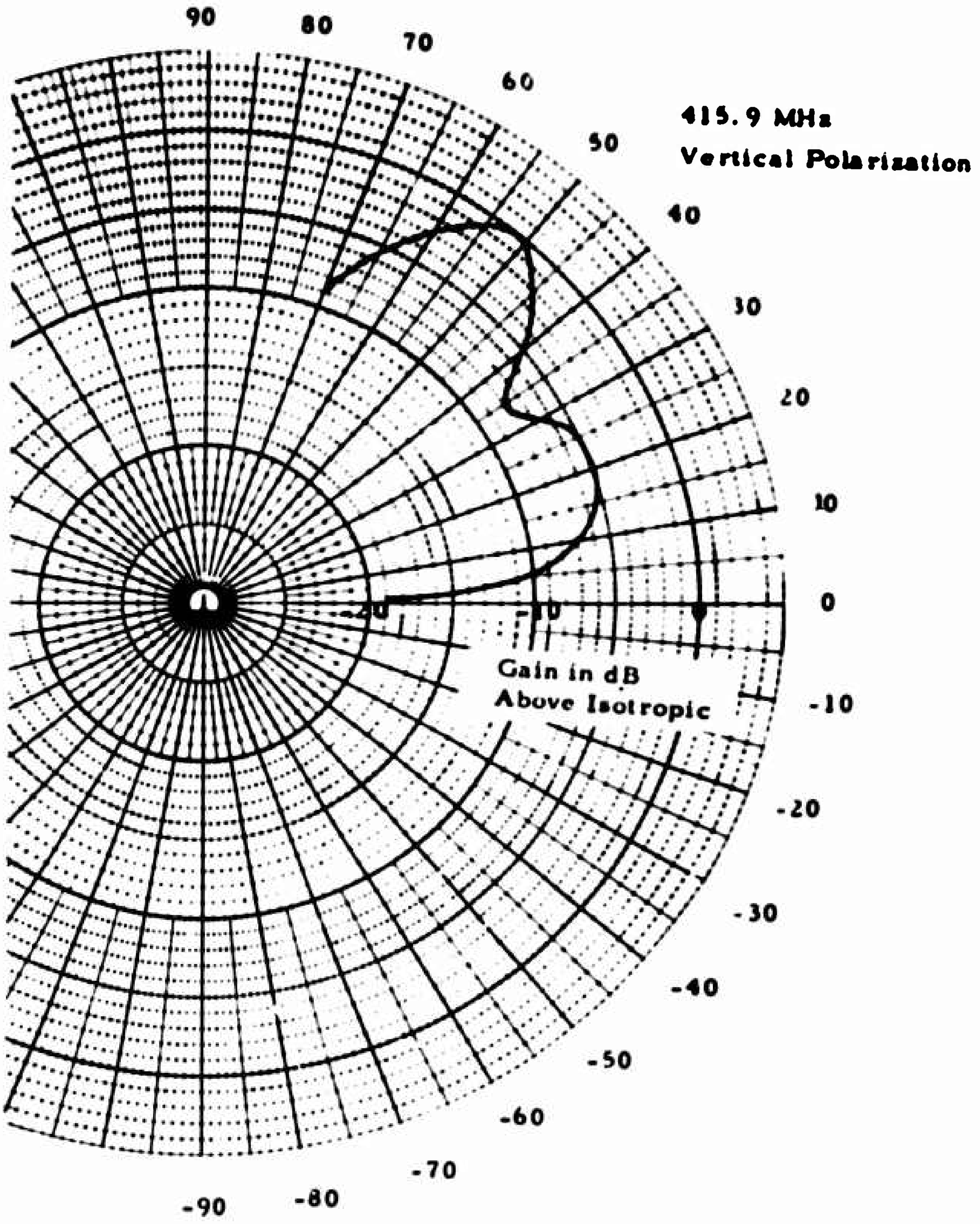

Figure 23. Site power gain pattern for the 1/4 wave monopole over a ground plane.

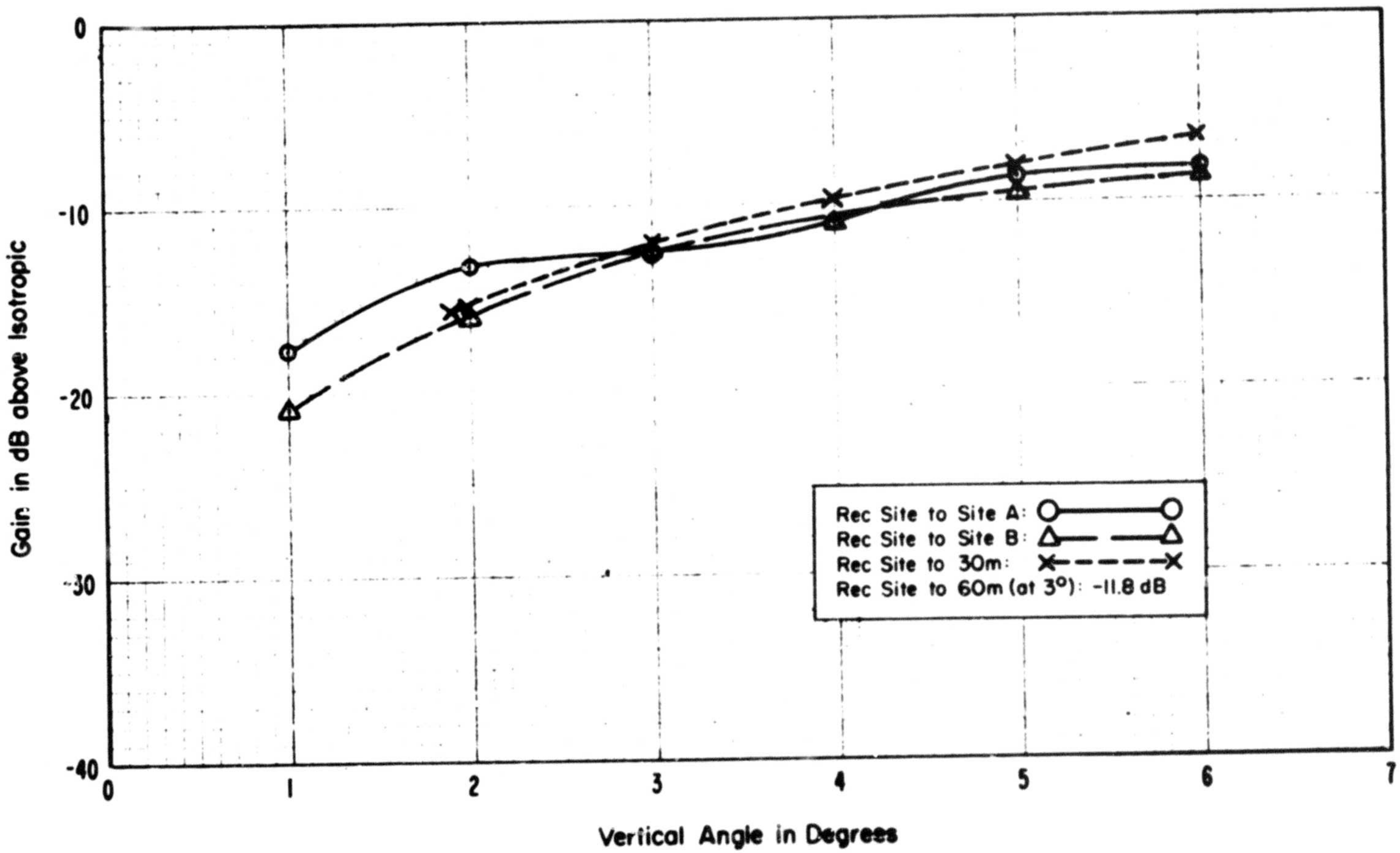

Figure 24. Site power gain of the annular slot antenna for distances of 0.03, 0.06, and 1 km.

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13. ABSTRACT

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